Systematic studies on α decay from the ground states of $^{170\text{-}195}$Hg isotopes

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Introduction

Current research in nuclear physics places significant emphasis on α-decay, as the study of α-decay chains enables the identification of heavy and superheavy nuclei by linking unknown nuclides to well-characterized ones. Such investigations provide reliable information on half-lives, shell effects, and nuclear deformation. To complement experimental efforts, various theoretical models and empirical formulas are employed to predict α-decay half-lives.

This study explores alpha emissions from the ground states of Hg isotopes using the modified Generalized Liquid Drop Model (MGLDM) [1], developed by Santhosh et al., and compares it with experimental values. Also, we improved the SemFISS formula [2], known as the Improved SemFISS formula, by including the angular momentum contribution, and the half-lives are calculated and compared with the other results.

MGLDM (Modified Generalized Liquid Drop Model)

The total energy for a deformed nucleus can be expressed as,

$$E = E_V + E_S + E_C + E_R + E_P \tag{1}$$

Where, E_V denotes the volume energy, E_S, the surface energy, and E_C, E_R , and E_P denotes Coulomb, rotational, and proximity energies.

The proximity potential, introduced by Blocki et al. [3],

$$E_p(z) = 4\pi\gamma b\left[\frac{C_d C_\alpha}{C_d + C_\alpha}\right]\phi\left(\frac{z}{b}\right) \tag{2}$$

The penetration probability of α-particle through the barrier, *P,* is computed using the expression [4],

$$P = e^{\left\{-\frac{2}{\hbar}\int_{R_{in}}^{R_{out}}\sqrt{2B(r)[E(r)-E(sphere)]}dr\right\}} \tag{3}$$

The relation connecting the partial half-life with the decay constant λ, the preformation factor P_α, and the assault frequency ν is given by,

$$T_{1/2} = \frac{ln\,2}{\lambda} = \frac{ln\,2}{\nu P_\alpha P} \tag{4}$$

ISFF (Improved SemFISS Formula)

Considering the angular momentum factors, the semi-empirical formula [2] based on fission theory can be improved, and the revised formula is given by,

$$\log_{10} \mathrm{T}_{1/2}\,(\mathrm{s}) = 0.43429\mathrm{K_s}\chi + \mathrm{a}\frac{\mathrm{l(l+1)}}{\sqrt{\mathrm{A_d Z_d A^{-2/3}}}} + \mathrm{b} \tag{5}$$

with a = 2.092911 and b = -19.378485.
Where K_s is the WKB penetrability term corresponding to the separated fragments. And,
$\chi = B_1 + B_2 y + B_3 z + B_4 y^2 + B_5 yz + B_6 z^2$
Here, the B_k values are taken from Ref. [5], and the relative distances of the neutron number and proton number from the respective closest magic-plus-one numbers are y and z.

Results and discussion

We analysed the isotopes of mercury (Hg) within the mass range of A = 170 to 195, which undergo alpha decay and transform into the daughter nuclei $^{166\text{-}191}$Pt. The half-lives of these isotopes were calculated using the modified Generalized Liquid Drop Model (MGLDM) and then compared with experimental data. The results showed a strong agreement, confirming the model's reliability. Additionally, we refined the semi-empirical fission-based formula (SFF) by incorporating angular momentum effects, leading to an improved version known as the Improved SemFISS formula (ISFF). The half-lives were then calculated using this enhanced approach and compared with the experimental values. The disintegration energy can be

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*Electronic address: *anjalinarayanan01@gmail.com* abbreviated as Q-value, which can be taken from the Ref. [6].

Table 1 Predictions of alpha decay half-lives from $^{170-195}$Hg with $^{166-191}$Pt as daughter nuclei.

Parent nuclei	Q-value (MeV)	$\log_{10}[T_{1/2}(s)]$		
		Expt.	MGLDM	ISFF
^{170}Hg	7.77	-3.50	-3.96	-3.34
^{171}Hg	7.66	-4.15	-3.49	-3.88
^{172}Hg	7.52	-3.63	-3.25	-2.64
^{173}Hg	7.38	-3.09	-2.75	-3.64
^{174}Hg	7.23	-2.69	-2.35	-1.76
^{175}Hg	7.07	-1.99	-1.77	-2.65
^{176}Hg	6.89	-1.64	-1.23	-0.67
^{177}Hg	6.74	-0.93	-0.51	-0.86
^{178}Hg	6.58	-0.52	-0.08	0.46
^{179}Hg	6.35	0.14	0.85	0.02
^{180}Hg	6.26	0.73	1.15	1.69
^{181}Hg	6.28	1.12	1.18	1.05
^{182}Hg	5.99	1.89	2.24	2.78
^{183}Hg	6.04	1.90	2.07	1.56
^{184}Hg	5.66	5.19	3.76	4.30
^{185}Hg	5.77	2.91	3.25	2.89
^{186}Hg	5.20	5.71	6.08	6.62
^{187}Hg	5.23		6.07	6.36
^{188}Hg	4.71		8.99	9.54
^{189}Hg	4.64		9.67	10.67
^{190}Hg	4.07		13.55	14.12
^{191}Hg	3.67		17.05	17.26
^{192}Hg	3.38		19.83	20.45
^{193}Hg	2.98		24.58	25.29
^{194}Hg	2.69		28.45	29.20
^{195}Hg	2.26		36.06	38.14

To assess accuracy, we determined the standard deviations of the computed half-lives. For the MGLDM calculations, the standard deviation was found to be 0.50, while for the ISFF method, it was 0.69, indicating a reasonable consistency between theoretical predictions and experimental results [7]. The difference between the experimental and the computed half-lives against neutron number is plotted, where most of the values lie within -1 and +1. Additionally, the half-lives of the nuclei in the range ^{187}Hg to ^{195}Hg are predicted, which have not yet been experimentally verified. The linear nature of the Geiger-Nuttal plot [8] and the New Geiger-Nuttal plot [9] can be observed. The New G-N plot, which accommodates both favoured and unfavoured alpha transition on a single linear curve, is expressed as,

$$log_{10}T_{1/2} = A(Z_d^{0.8} + \ell^{0.5})Q_\alpha^{-1/2} + B \quad (6)$$

where, A= 3.84 and B=-49.41.

which enhances the valuability of our model.

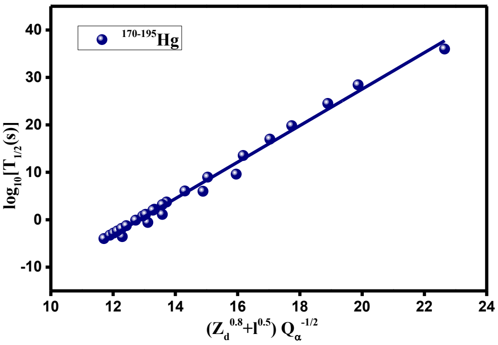

Fig. 1 New Geiger-Nuttal plot

Also, the least value of standard deviations suggests that the present formalism can effectively be used for alpha decay studies of heavy nuclei.

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References

[1] K.P. Santhosh, C. Nithya, et al., Phys. Rev. C **98**, 024625 (2018)

[2] D.N. Poenaru, I. H. Plonski, and W. Greiner, Phys. Rev. C **74**, 014312 (2006).

[3] J. Blocki, J. Randrup, et al., Ann. Phys. (N.Y.) **105**, 427 (1977).

[4] G. Royer and B. Remaud, J. Phys. G: Nucl. Part. Phys. **10**, 1057 (1984).

[5] D.N. Poenaru, M. Ivascu and D. Mazilu, Comp. Phys. Commun **25**, 297 (1982)

[6] M. Wang, W.J. Huang, et al., Chinese Phys. C **45**, 030003 (2021).

[7] https://www.nndc.bnl.gov/nudat3/

[8] H. Geiger and J. M. Nuttall, Phil. Mag. **22**, 613 (1911)

[9] V. K. Anjali and K. P. Santhosh, Phys. Scr. **98**, 105303 (2023)